A New Approach to Measuring Rock Properties Data from Cores and Cuttings for Reservoir and Completions Characterization: An Example from the Bakken Formation*

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Abstract

The application of rock physics data for improved reservoir characterization is well known and documented and can help to delineate fluid and facies changes down the borehole. With the advent of unconventional resource exploration and production, and the adoption of long laterals to maximize reservoir contact and recovery, use of elastic rock properties for completions characterization becomes increasingly important.

Traditionally, rock elasticity has been determined through geomechanical laboratory measurements on core pieces or plugs and log derived calculations. Unfortunately, these data sets are rare (i.e. core) and inconsistent/expensive to collect (i.e. logs) along long laterals. However, cuttings are always available for the entire borehole. They provide a source of compositional and textural rock data that can be quantitatively measured to train standard petrophysical analysis in order to implement rock physics equations (e.g. Young's Modulus, ν, λ, $\lambda-\rho$, and $\mu-\rho$). Using electron beam (e-beam) systems, such as RoqSCAN™, mineral composition data, together with high resolution textural information (e.g. pore volume, pore fabric, pore size distribution and pore aspect ratio) within cuttings are now directly measureable. This allows for input parameters (e.g. pore aspect ratio) to be directly measured within rocks rather than mathematically derived.

Method

The first phase of this project involved the collection of all available well log data for well Sidonia-106H, which penetrated the Bakken Formation in Montrail County, North Dakota, by EOG Resources Inc. The well logs retrieved included a Gamma Ray, Sonic, Resistivity, Neuton Porosity and Density. These logs were loaded into a petrophysical modeling package, PowerLog®, and through the use of stochastic modeling a mineralogical composition of the well was calculated based on the well logs input. The Statmin model also calculated kerogen, bound water and bound oil content within the Bakken Formation. Based on the results from the stochastic model the formation was separated into Upper, Middle and Lower Bakken. The resultant model output for the vertical section intersecting the Bakken Formation is shown in Figure 1. The log clearly shows the modeled mineralogy of the Upper and Lower Bakken being predominately clay rich with secondary sand (quartz), while the Middle Bakken is classified as dolomitic sandstone. Using the modeled mineralogical composition, PowerLog® was then used to calculate various elastic rock properties, including Young's Modulus and Poisson's Ratio (Figure 1). The results from this initial log data modeling shows a clear difference in the acoustic properties within the Upper and Lower Bakken compared to the Middle Bakken. However, though there are features with some of the derived elastic properties, λ and Young's Modulus, the Poisson's Ratio does not reflect the same level of detail, hosting only minor dips and peaks within a relatively continuous trace.

The second phase of the project involved the collection of 424 cuttings and core samples from the Sidonia-106H vertical and lateral wells. The vertical well samples corresponded to the well logs used during the first phase of the project. For the purpose of this presentation only samples from the vertical section intersecting the Bakken Formation will be discussed. All 424 cuttings and core samples were screened for contaminants and cavings prior to embedding into a 30 mm two-part epoxy resin round block, which was then polished. The polished resin block was carbon coated before introduction into the sample chamber of the RoqSCAN™, and evacuated to a high vacuum.

The RoqSCAN™ is an e-beam analytical instrument based on a ruggedized mobile Scanning Electron Microscope (SEM) platform. These instruments are all fully automated, designed to start-up, calibrate and determine the mineralogical and textural features of rock samples. These e-beam techniques generate mineralogical information, retaining the spatial location within the measured sample/particle (core or ditch cuttings). Currently, RoqSCAN™ analysis is unique as it also provides textural pore system information such as pore size, shape and aspect ratio. Figure 2 shows an example of two distinct pore structures within the Upper and Lower Bakken Formation. Porosity values and mineralogy for the Upper and Lower Bakken are generally very similar, but these two images clearly show a significant difference in the pore shape and structure. Utilizing the full capability of RoqSCAN™, mineralogical and pore textural properties of the cuttings and core samples of the Bakken Formation were quantified. The results of this analysis are shown as a data summary chart in Figure 3.

Results

The data summary chart (Figure 3) provides data on the bulk mineralogy of the Bakken Formation within the Sidonia-106H vertical well (track 4). This shows quartz and clay rich compositions in the Upper Bakken, while the Lower Bakken contains higher clay contents with a sandstone stringer located in middle of the section. The Middle Bakken is shown to be carbonate rich; however, unlike the log based model this data shows a mixed calcite/dolomite sandstone rather than a dolomitic sandstone. The following 23 logs on the data summary chart (logs 5-28) provide a breakdown of the individual minerals used to construct the bulk mineral data (log 4). Based on the individual minerals, the Middle Bakken Member also shows an elevated rutile/anatase and zircon composition relative to the Upper and Lower Bakken, indicating an alteration in depositional environment i.e. closer proximity to terrigenous source. Additionally, the Upper and Lower Bakken show a high pyrite concentration, relative to the Middle Bakken, the sulphur of which is a good proxy for organic content in these two sections. The following 11 logs (logs 29-40) contain elemental ratios for provenance, marine and organic proxies. Finally the last 4 logs contain an index of porosity, a distribution of pore size, arithmetic average pore aspect ratio and a mineralogical derived brittleness index (i.e. RoqFRAC), respectively. The data from these last four logs show that though the mineralogical composition of the Upper and Lower Bakken are similar, and the porosity index for both these section are elevated relative to the Middle Bakken, the physical space and size of the pores are vastly different (as per the measured pore size distribution and pore aspect ratio).

The final phase of the project involved using the directly measured rock data, produced by RoqSCAN™, as additional inputs into the petrophysical model. The original stochastic model generated by PowerLog®s' StatMin module was modified to a deterministic model using this rock-derived mineralogical data as end points. The result of the recalculation to the model is shown in Figure 4, and shows a better agreement between the log-derived mineralogy and the rock-measured mineralogy. The most significant change occurs within the Middle Bakken which now records greater calcite content rather than purely dolomite, while the Lower Bakken now shows a similar quartz pattern to the measured data rather than the flat consistent quartz signature based on logs alone. In addition to using the rock derived mineralogical data, the pore aspect ratio and porosity values were also applied to the new model to better characterize the elastic properties of the drilled rocks. A new set of elastic properties curves were generated (Figure 4), which is both similar and significantly different from the original model data (Figure 1). The main feature in the new set of curves is the clear presence of a brittle zone (Rock type 4b, Figure 4), at the base of the Upper Bakken, which is not present in the original data (Figure 1).

Finally the textural data were applied to the new model to better characterize the hydrocarbon content within the borehole. This was achieved by applying the measured values of the pore aspect ratio and porosity, and modeling the P and S wave velocity by modification of the hydrocarbon content in each section. The result of which, shown in Figure 4, is an increase in kerogen concentration as compared to the previous stochastic model calculated for the Upper and Lower Bakken, known to be hydrocarbon rich.

Conclusions

Making use of the improved input model for the well logs, the results from the projects clearly show that through the use of directly measured rock data (mineralogical and textural), better understanding of the elastic properties throughout the borehole can be determined. The ability of e-beam technology generating this rock based data, not just for vertical but also for lateral wells, opens up the possibility of using mineralogical data to better predict elastic properties throughout lateral wells and thus improving hydraulic fracturing placements. This aims to create non-geometric hydraulic fracture designs, utilizing differences in rheology to better space completions, with differences in mineralogy to aid in hydraulic fracture fluid and proppant design to maximize recovery of each stage.

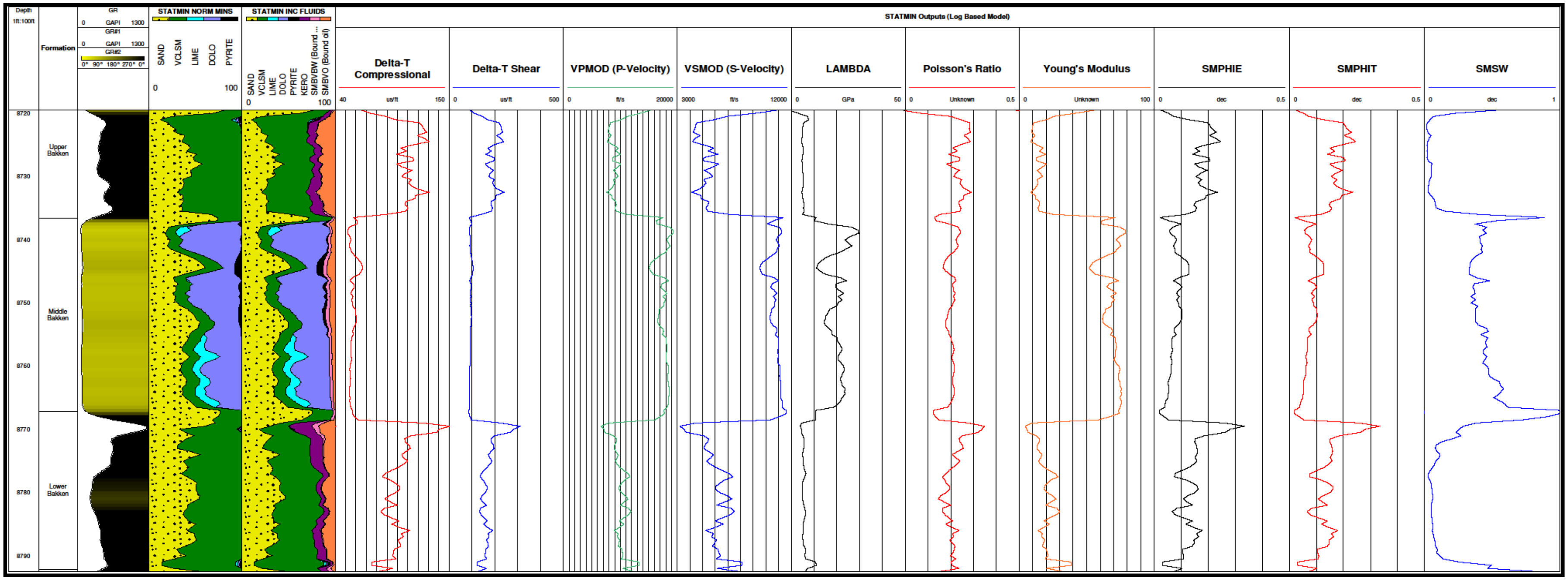

Figure 1. Bakken log-based mineralogical model and elastic rock properties.

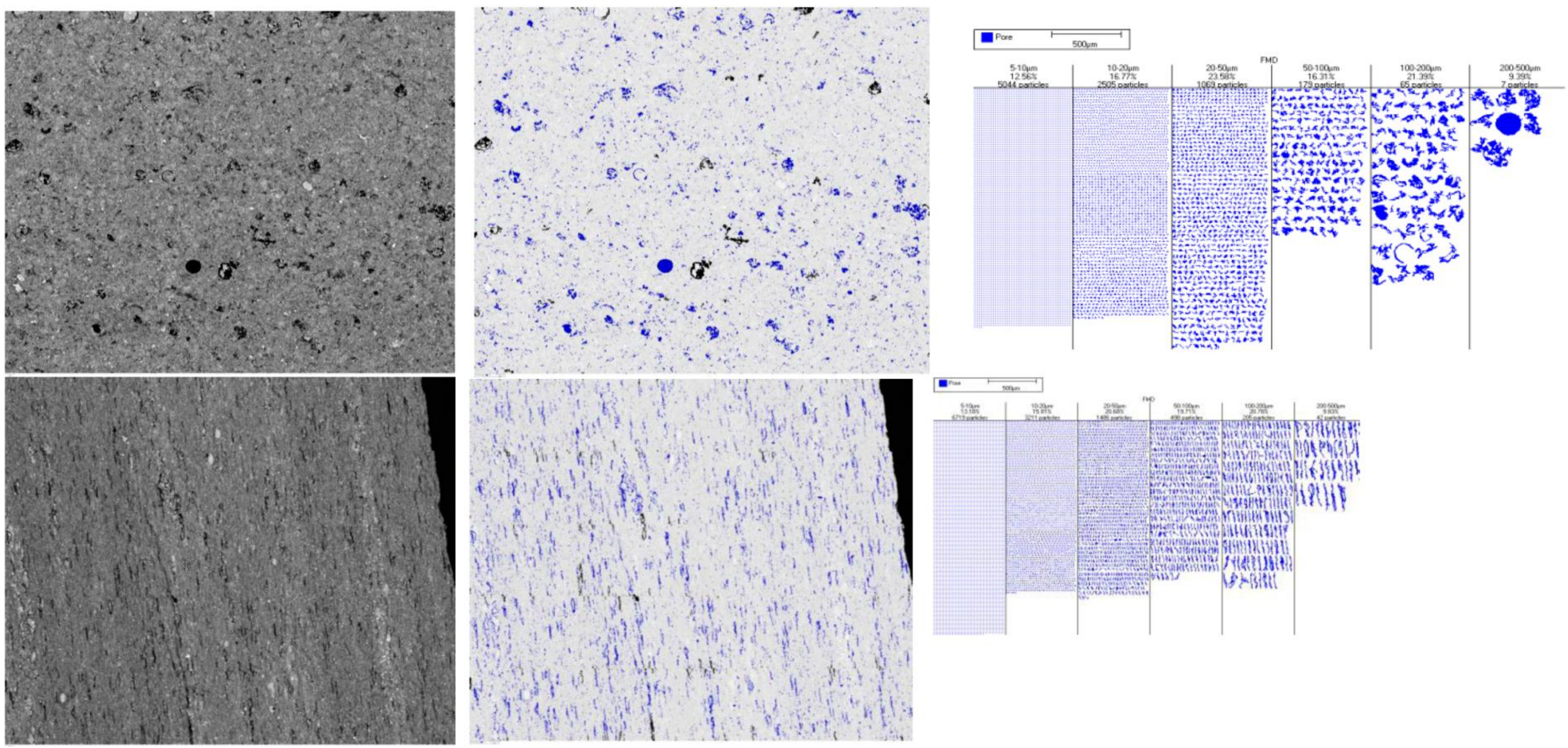

Figure 2. Pore textural output from automated mineralogical instrument (RoqSCAN example shown). Upper Panel – pore structure measured in Upper Bakken Formation. Lower Panel – pore structure measured in Lower Bakken Formation.

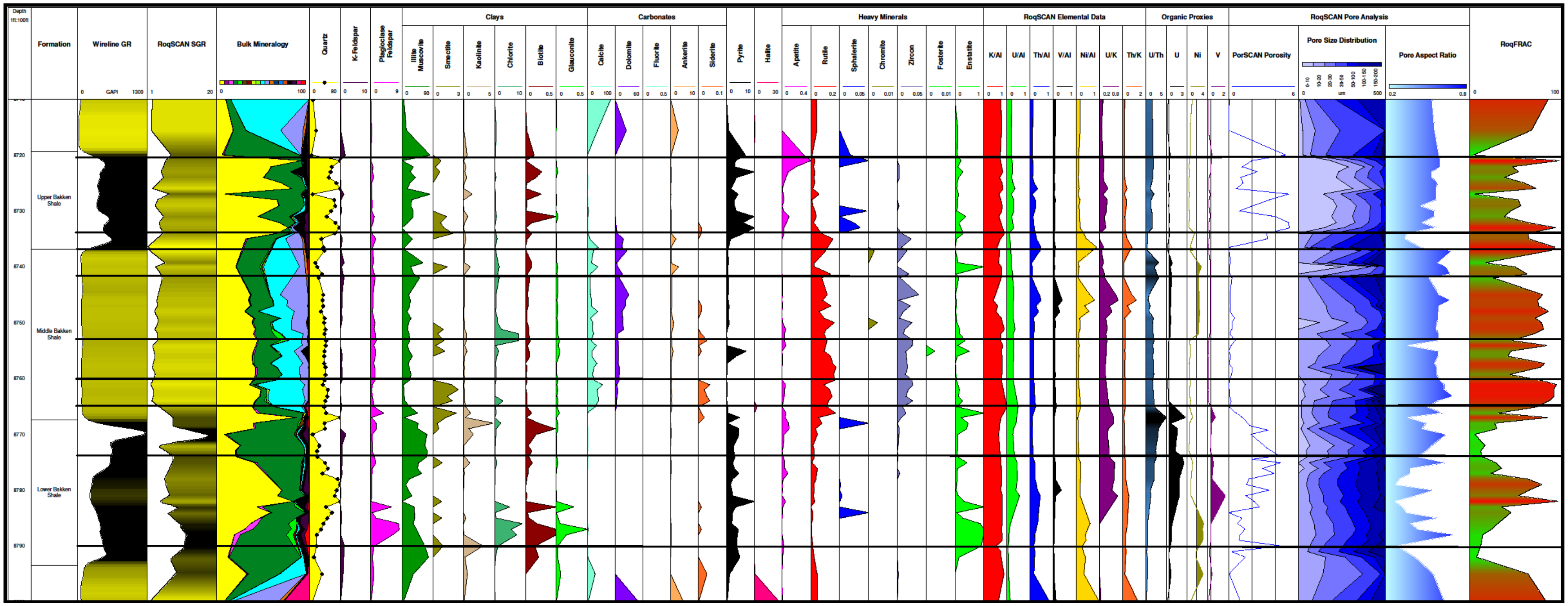

Figure 3. Data summary chart from the RoqSCAN analysis of cuttings and core samples from the Sidonia 1H well.

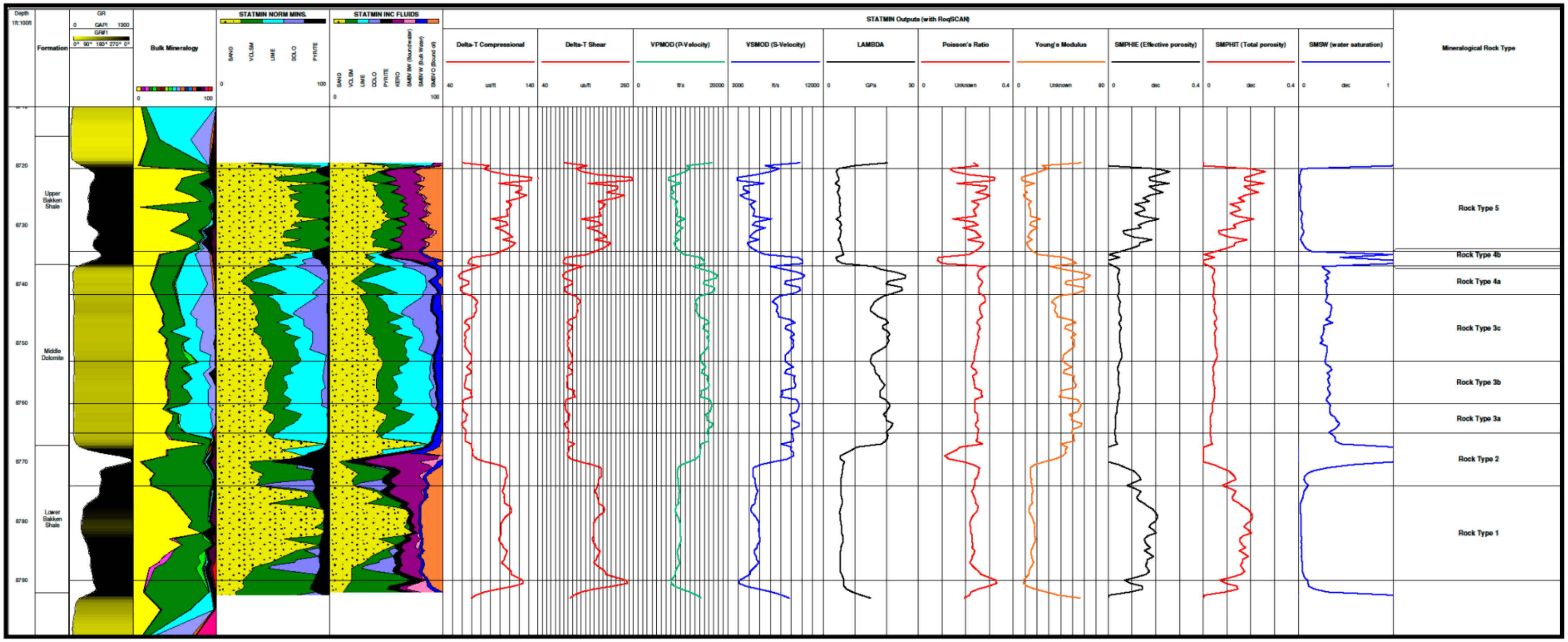

Figure 4. Recalculated mineralogical and elastic properties from the Sidonia 1H well using measured rock mineralogical data as the end point for a deterministic log-based modeling.